

## **Leveraging the MJO for Predicting Envelopes of Tropical Wave and Synoptic Activity at Multi-Week Lead Times**

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### **LONG-TERM GOALS**

The Madden-Julian Oscillation (MJO) is the dominant mode of tropical intraseasonal variability, and it extensively interacts with other components of the climate and weather systems. In this project, we will focus on its interactions with important higher-frequency tropical modes. The long-term goals are 1) to explore the relationships between the MJO and the tropical synoptic variability, mainly the convectively coupled equatorial waves (CCEWs) that include Kelvin, equatorial Rossby, mixed Rossby-gravity, Inertio-gravity waves, and tropical depressions; 2) to investigate the physical mechanisms behind these relationships; 3) to explore the predictability and prediction skill of the envelopes of these tropical synoptic waves associated with the MJO, thus contributing to forming a seamless bridge between weather and climate prediction.

### **OBJECTIVES**

The main objectives of this project are listed below.

A. Explore and characterize the observed relationships between the MJO and organized synoptic variability in the tropics, including lead-lag relationships and implied predictability as well as characterizing the physical mechanisms behind these relationships.

B. Utilize two state-of-the-art multi-model experimental archives\* to assess the capabilities of present-day forecast models and GCMs to simulate and forecast the MJO, tropical synoptic variability, and their relationships on intraseasonal time scales.

\*the two archives: 1) MJO Task Force & GEWEX GASS MJO Diabatic Heating Experiment, 2) Intraseasonal Variability Hindcast Experiment (ISVHE)

C. Conduct more comprehensive analysis on the NOAA/GFDL HiRAM (climate) and NAVGEM (weather forecast) GCMs to more fully characterize these models' fidelity in simulating and forecasting MJO – synoptic variability relationships and their depiction of the intrinsic predictability of tropical transient wave activity on intraseasonal time scales.

### **APPROACH**

In order to achieve the goals listed above, we will be analyzing various datasets including satellite observations such as the TRMM rainfall, reanalysis datasets such as the ERA-Interim reanalysis, and

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two archives of state-of-the-art multi-model experiments. We will compare the results based on the observations and reanalysis with the model simulations to assess the current model performance in capturing the observed relationships between the MJO and the tropical synoptic variability. Finally, we will conduct some specific sensitivity tests using the NOAA/GFDL HiRAM (climate) and NAVGEM (weather forecast) GCMs to better understand the results we will get from the observations and multi-model simulations.

The project is led by D. Waliser (UCLA/JPL: PI) and X. Jiang (UCLA/JPL: co-PI). Waliser and Jiang have had a very productive collaboration over the last five years, resulting in at least 10 publications, on topics of tropical climate variability, multi-scale interactions and physical process understanding. In addition, the team and project will benefit greatly from the involvement/leadership of Waliser and Jiang in the establishment of the two sets of model experiments described in the OBJECTIVES. Additional core team members include Y. Guo (UCLA/JPL postdoc) who will carry out a significant fraction of the analyses. Guo has published several papers on climate dynamics and climate variability since her Ph.D. study. Key partners include M. Zhao (GFDL) and J. Ridout (NRL). Both Zhao and Ridout are contributors to the MJO multi-model diabatic heating experiment (one of the model archives listed in the OBJECTIVES).

## **WORK COMPLETED**

During the first year, we have downloaded the relevant datasets to carry out the observational component of the analysis listed in OBJECTIVE A, including satellite observations (e.g., TRMM3B42 rainfall), and reanalysis datasets (e.g., ERA-Interim dynamical and thermodynamic parameters).

We have conducted analysis on the observed relationships between the MJO and the tropical wave and synoptic activity, focusing on the convectively coupled equatorial waves (CCEWs). The major results have been written up as a paper and submitted to the Journal of the Atmospheric Sciences (Guo et al. 2013).

We have also begun acquiring model data from the MJO Diabatic Heating Experiment and the ISVHE data archives in order to commence objective B in Year 2.

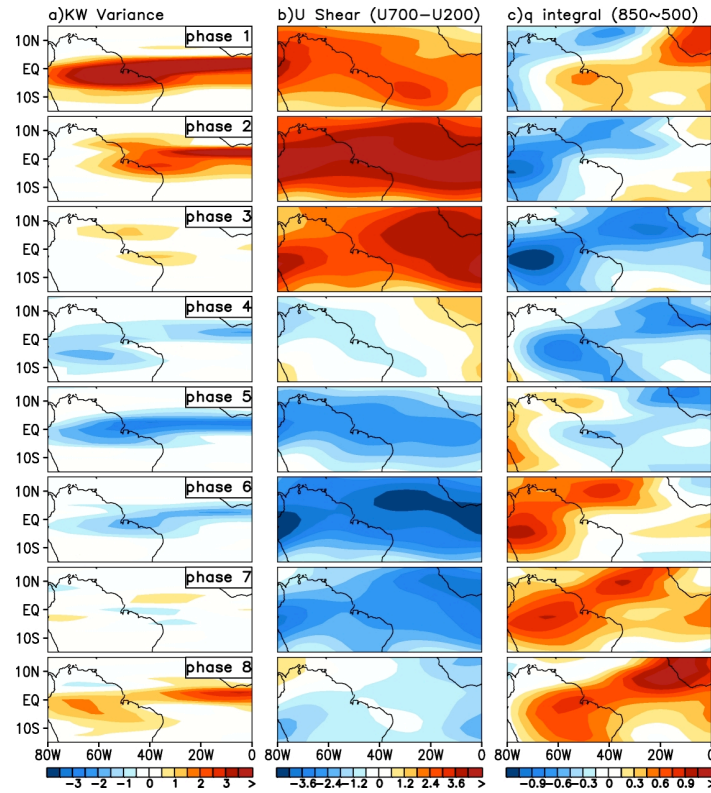
## **RESULTS**

Firstly, the convection signals of the MJO and each CCEW were isolated by filtering the 14-year (1998-2012) TRMM rainfall based on the specific spectra of the wavenumber-frequency domain that corresponds to a particular mode. Then, the variance of the CCEWs in TRMM data was composited for the eight MJO phases according to the daily all-season real-time multivariate MJO (RMM) index to examine the modulation of the MJO on the CCEWs activity. Strong modulation of the CCEW activity by the MJO was found: CCEW activity is significantly enhanced within the envelope of the active MJO convection, while it is significantly reduced within the envelope of the suppressed MJO convection. This modulation by the MJO can lead to more than 20% change in the strength of the CCEW activity relative to its climatology. Nevertheless, enhancement/suppression of the CCEWs is also found in some regions away from the MJO convection centers.

Besides examining the modulation by the MJO on all types of CCEWs, we have especially focused on its modulation of the convectively coupled Kelvin waves (CCKWs) at this stage. Kelvin waves are a particularly important wave mode in the tropics, and have a close relation to the MJO. Early theories

for the MJO portrayed it as an equatorial Kelvin wave whose properties were modified by the coupling between the convection and large-scale circulation, and many marginally successful models for the MJO were based on moist Kelvin wave dynamics, although more recent studies suggested that the MJO and the Kelvin wave behave differently in many respects. Close examination of the interactions between the MJO and the Kelvin waves is thus highly desirable. Moreover, we have focused on the South America and tropical Atlantic region (80 to 0°W, and 15°S to 15°N) since the CCKW convection variance exhibit a local peak value over this region with a magnitude comparable to that in the western Pacific warm pool region on both climatological and intraseasonal time scales; and few studies have examined the modulation of CCKWs by the MJO over this specific region.

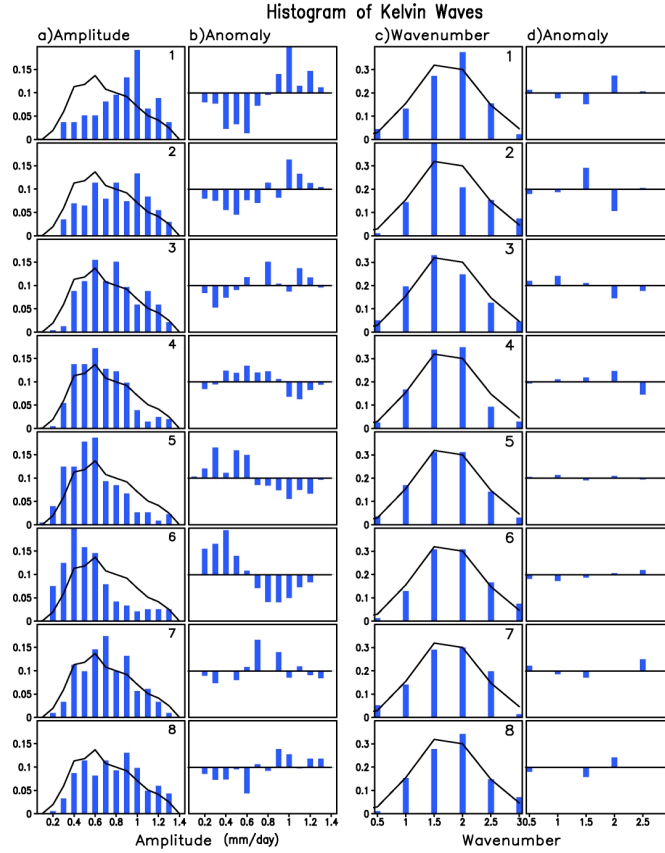
It is found that the Kelvin wave variance over the South America and tropical Atlantic region are increased during MJO phases 8, 1, and 2, while they are reduced during MJO phases 4, 5, and 6. In particular, strongest positive (negative) Kelvin wave activity anomalies appear in phase 1 (5). See Figure 1a.



**Figure 1: Eight-phase MJO composite patterns of (a) the 30-96day filtered CCKW variance (unit:  $\text{mm}^2 \text{day}^{-2}$ ), and the MJO-filtered (b) vertical shear of zonal wind between 700hPa and 200hPa (unit:  $\text{m s}^{-1}$ ) and (c) specific humidity integrated from 850hPa to 500hPa (unit: kg).**

We further examined the variation in the wave amplitude and wavenumber of individual Kelvin waves in different MJO phases. Figure 2 shows the histograms of the wave amplitude and wavenumber of CCKWs for each MJO phase superimposed on the climatological distribution. Comparing to the climatology, it is found that the wave amplitude exhibits a clear shift toward stronger amplitude in phases 8, 1, and 2: with a larger (smaller) percentage of days with relatively strong (weaker) amplitudes than climatology (Figs. 2a and b). On the contrary, the wave amplitude shifts toward

weaker amplitudes for phases 4, 5, and 6. In contrast, Figs. 2c and d indicate that there is not much variation in the wavenumber distribution across the eight MJO phases: the histograms for all phases follow the climatological distribution quite closely. In addition, the MJO is also found to exert some modulation on the vertical tilt of the Kelvin waves (not shown).

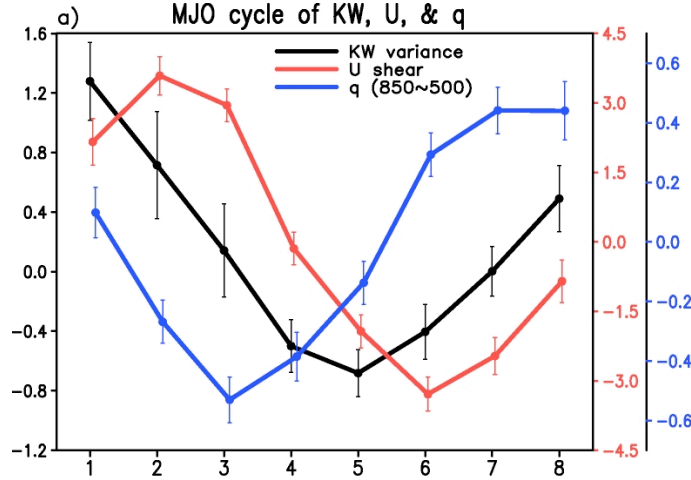


**Figure 2: The histograms of the daily Kelvin wave (a) amplitude (unit:  $\text{mm day}^{-1}$ ) and (c) wavenumber averaged over  $80^{\circ}\text{W}$ - $0^{\circ}\text{W}$ , and  $15^{\circ}\text{S}$ - $15^{\circ}\text{N}$  during 1998-2012 for the eight MJO phases, with the climatological histograms (black curves) superimposed. Y axis is the percentage of total number of days in each wave amplitude or wave number bin. The anomalies of the amplitude and wavenumber relative to the climatology are shown in (b) and (d), respectively.**

We further examined some possible physical processes through which the MJO might modulate the CCKW activity over this region. Our analyses suggest that the strong modulation of the MJO on the CCKW activity could be largely due to two physical factors, namely, the vertical zonal wind shear (Figure 1b) and the lower-middle tropospheric specific humidity (Figure 1c). The CCKW activity tends to be enhanced during MJO phases when the MJO-filtered vertical wind shear is easterly (easterlies in the upper troposphere and westerlies in the lower troposphere) and the MJO-filtered lower to mid-troposphere moisture anomalies are positive, and vice versa. These two physical processes associated with the MJO are found to have positively (negatively) reinforcing influences on the CCKW activity in phase 1 (4 and 5), while counteracting influences in phases 2, 3, 6, 7, and 8, leading to the observed MJO cycle of the CCKW activity anomalies in the study region (Figure 1).

The above results were further summarized in Figure 3, in which the CCKW variance, the MJO-filtered vertical wind shear and lower-middle troposphere moisture content anomalies in each phase

are averaged over the South America and tropical Atlantic region (15°S - 15°N, 80 - 0°W). Figure 3 clearly illustrates that the competition between the wind shear and lower-middle water vapor content produces the observed MJO cycle of the CCKW activity. The vertical wind shear has a variation lagging about one phase behind that in the CCKW activity, while the water vapor content shows a variation leading about two phases ahead of it. Again we emphasize that the cancellation between the two factors in phases 2, 3, 6, 7, and 8 as well as the reinforcement between them in phases 1, 4, and 5 overall produce the MJO cycle of the CCKW anomalies.



**Figure 3:** The MJO cycle of the 30-96day filtered CCKW variance (black, unit:  $\text{mm}^2 \text{day}^{-2}$ ), the MJO-filtered vertical shear of zonal wind between 700hPa and 200hPa (red, unit:  $\text{m s}^{-1}$ ), and specific humidity integrated from 850hPa to 500hPa (blue, kg). The error bars denote the 99% confidence level of the means based on a one-tail Student's *t* test.

Our results indicate that in certain MJO phases, the large scale dynamical and thermodynamical conditions associated with the MJO favor or suppress the growth of the CCKWs over South America and tropical Atlantic region. Given the close relationship between the CCKWs and the local as well as downstream weather, the findings in this study have broader implications on extended-range predictability of weather/climate variability. Given predictability of the MJO out to about four weeks, and continuous improvement of the predictive skill for the MJO in current general circulation models, the results in this study indicate how such predictability might be leveraged for forecasting CCKW activity and related tropical waves and synoptic disturbances over this region. In addition, in light of the potentially important role of the CCKW in the initiation of the MJO over the western equatorial Indian Ocean, a better understanding of the CCKW as illustrated in this study will further lead to improved MJO forecast skill.

## IMPACT/APPLICATIONS

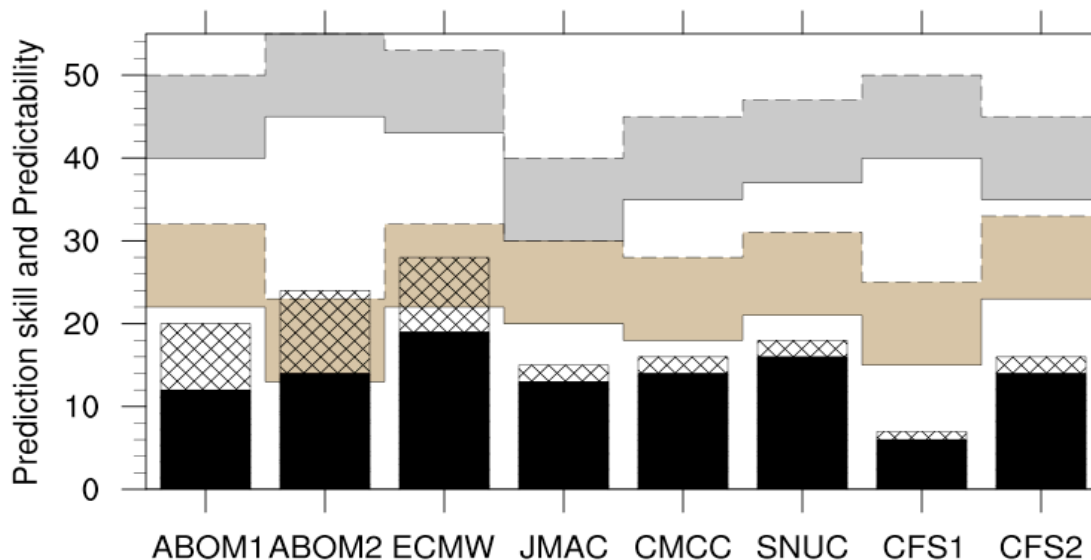
The examination of the relationship between the MJO and the convectively coupled equatorial waves is an important topic for our understanding of the possible interactions across scales between the planetary scale MJO envelope and the imbedded synoptic scale waves. Up to now little attention has been given to this crucial topic by the scientific community. Our research has yielded observational evidence on how the slower mode (the MJO) interacts with the faster tropical wave modes, thus providing valuable insights to the climate dynamics and modeling communities.

Furthermore, given the predictability of the MJO out to a few weeks, and continuous improvement of the predictive skill for the MJO in current general circulation models, our results on the relationships between the MJO and convectively coupled equatorial waves have important implications for extended-range prediction of tropical synoptic waves, thus contributing to bridging the prediction between weather and subseasonal time scales.

## RELATED PROJECTS

Two very closely related efforts are worth mentioning, each involving one of the community modeling activities mentioned above in WORK COMPLETED and highlighted in the proposal. Each of these benefits from the study and discussions associated with the above results and vice versa. This occurs through the joint supervision of these projects by Dr. Waliser and Dr. Jiang and through weekly group meetings where these topics are jointly discussed.

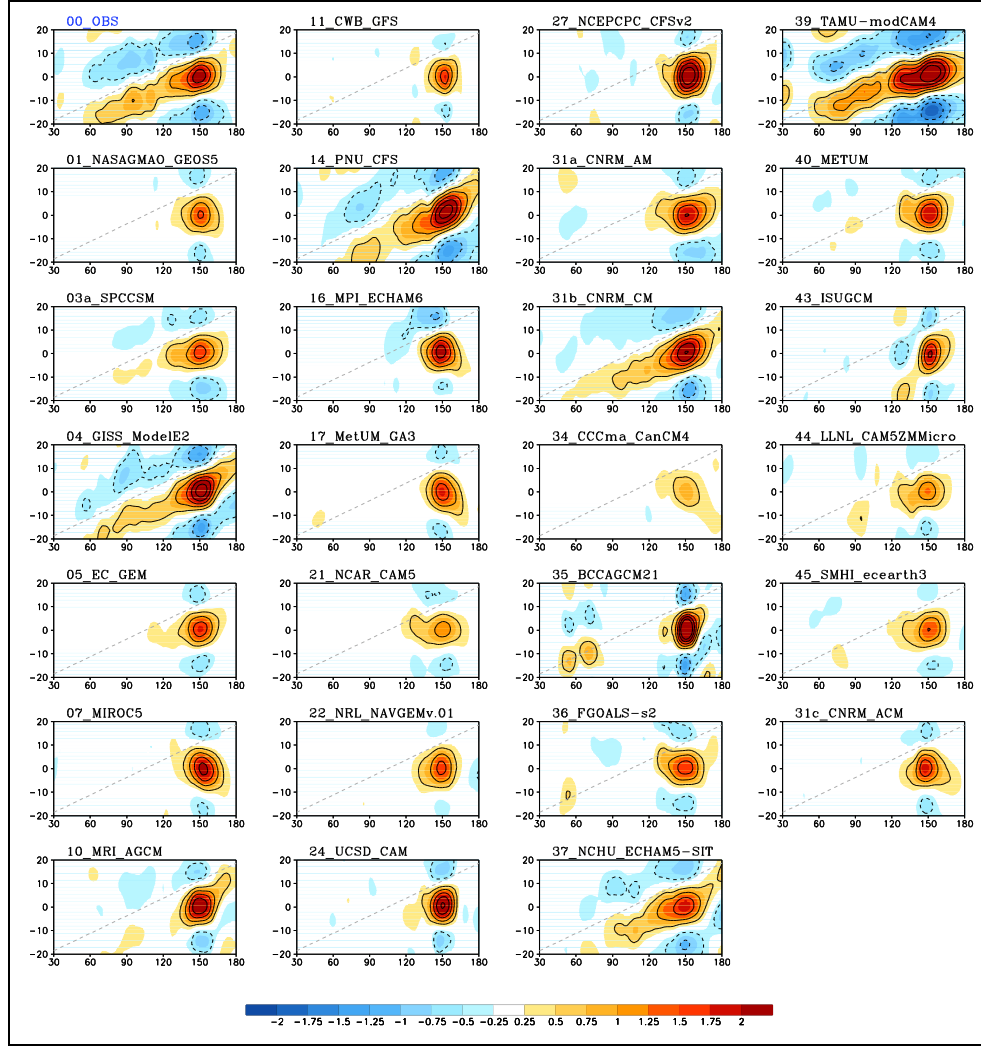
The first is analysis already being carried out on the ISV Hindcast Experiment (ISVHE). Under the guidance of co-PIs Waliser and Jiang, and consultations with Dr. Guo, our colleague/postdoc Dr. Neena Mani has carried out a predictability study on the MJO using ISVHE. Figure 4 highlights a summary of the results, illustrating a comparison between MJO model hindcast skill (model compared to observations) for single hindcast members (black bars), the improvement when using the model ensemble (hatched), then the estimate of predictability (twin idealized predictions, i.e. model compared to model) for single members (tan bars), and the predictability when using the ensemble compared to a member (gray bars). This illustrates that for the most part there is significant room for improvement in our forecast models of the MJO. The results of this study will be submitted for publication in the coming month.



**Figure 4 :** Average prediction skill (black bar) and ensemble mean prediction skill (hatched bar) estimates for MJO for the eight models are shown along with the respective, deterministic (wheat shaded area) and ensemble (grey shaded area) estimates of MJO predictability (+/-5 range).



The second is the initial analyses being carried out on the MJO TF and GEWEX GASS MJO Diabatic Heating Experiment – or more generally the Multi-model Physics Experiment. This work is being led by Dr. Waliser and Dr. Jiang, with the analysis being mainly carried out by Dr. Jiang and our colleague Dr. Guan. Figure 5 highlights a summary of the multi-model comparison of the MJO, which is just one comparison and analysis in a wide spectrum of analyses that includes analyses of 2-day and 20-day hindcasts, and 20 year simulations. The results of this study will be submitted with two others (led by UKMO, U. Reading) and form the initial foundational results from this international community activity. Note NRL provided simulations for this activity.



**Figure 5 : Time-lag precipitation diagrams using a base point in the western Pacific on the equator and 150E for 20-year simulations for the models that contributed 20-year simulations to the MJO TF – GEWEX GASS multi-model MJO physics comparison project.**

## PUBLICATIONS

Guo, Y., X. Jiang, and D. Waliser, 2013: Modulation of the Convectively Coupled Kelvin Waves over South America and tropical Atlantic Ocean by the Madden-Julian Oscillation. J. Atmos. Sci. (submitted, under revision)